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IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant: Alexander A. Maltsev et al.
Patent No.: 7,336,597
Issue Date: February 26, 2008

Examiner: Flores, Leon
Group Art Unit: 2611
Docket No: 884.783US1

Title: SYSTEM AND METHOD FOR TWO CHANNEL FREQUENCY OFFSET ESTIMATION OF OFDM SIGNALS

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Richard Beck
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Richard Beck
Signature

Patent 7,336,597 PATENT

IN UNITED STATES PATENT AND TRADEMARK OFFICE

Patent No.:	7,336,597	Docket No:	884.783US1
Issue Date:	February 26, 2008	Patentee:	Alexander A. Maltsev et al.
Customer No.:	21186	Confirmation No.:	3498
Title	SYSTEM AND METHOD FOR TWO CHANNEL FREQUENCY OFFSET ESTIMATION OF OFDM SIGNALS		

REQUEST FOR CERTIFICATE OF CORRECTION

Commissioner for Patents
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It is requested that a Certificate of Correction be issued correcting printing errors appearing in the above-identified United States patent. A copy of the text of the Certificate in the suggested form are enclosed.

Issuance of the Certificate of Correction would neither expand nor contract the scope of the claims as properly allowed, and re-examination is not required.

As the error is that of the Patent Office, it is believed that no fee is due.

The Examiner is authorized to charge any additional fees or credit overpayment to Deposit Account No.19-0743.

Respectfully Submitted,

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Name

Richard Beck
Signature

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(Also Form PTO-1050)

UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO : 7,336,597 Page (1) of 1

DATED : February 26, 2008

INVENTOR(S) : Maltsev et al.

It is certified that errors appear in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

In column 10, line 46, in Claim 4, delete “freguency” and insert - - frequency - -, therefor.

In column 12, line 29, in Claim 17, delete “freguency” and insert - - frequency - -, therefor.

In column 13, line 12, in Claim 20, delete “freguency” and insert - - frequency - -, therefor.

In column 13, line 56, in Claim 23, delete “freguency” and insert - - frequency - -, therefor.

In column 13, line 57, in Claim 23, delete “freguency” and insert - - frequency - -, therefor.

In column 14, line 41, in Claim 24, after “first” delete “,”.

MAILING ADDRESS OF SENDER: PATENT NO. 7,336,597

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Issued Patent Proofing Form **File: 884.783US1**
Note: P = PTO Error **S = SLWip Error** **Proofread By: Pallavi (03/03/2008)**

US Serial No.: 10/675,240 **US Patent No.: US 7,336,597 B2** **Issued Dt.: Feb. 26, 2008**
Title: SYSTEM AND METHOD FOR TWO CHANNEL FREQUENCY OFFSET ESTIMATION OF OFDM SIGNALS
PR Instructions: Face Page, Claims and Abstract

Sr. No.	P/S	Original		Issued Patent		Description of Error
		Page	Line	Column	Line	
1	P	Page 4 Claims (07/20/2007)	Claim 5 Line 1	10	46	In Claim 4, delete "freguency" and insert - - frequency - -, therefor.
2	P	Page 7 Claims (07/20/2007)	Claim 19 Line 2	12	29	In Claim 17, delete "freguency" and insert - - frequency - -, therefor.
3	P	Page 8 Claims (07/20/2007)	Claim 22 Line 10	13	12	In Claim 20, delete "freguency" and insert - - frequency - -, therefor.
4	P	Page 10 Claims (07/20/2007)	Claim 26 Line 7	13	56	In Claim 23, delete "freguency" and insert - - frequency - -, therefor.
5	P	Page 10 Claims (07/20/2007)	Claim 26 Line 7	13	57	In Claim 23, delete "freguency" and insert - - frequency - -, therefor.
6	P	Page 4 Notice of Allowance and Fees Due (PTOL-85) (09/19/2007)	Claim 27 Line 22 (Examiner's Amendment)	14	41	In Claim 24, after "first" delete ",".

channel frequency offset estimator, such as estimator **200** (FIG. **2**) or estimator **300** (FIG. **3**), although other estimators are also suitable. Operation **404** may use the coarse frequency offset to control or adjust a frequency for down-converting an IF signal to in-phase (I) signals and quadrature phase (Q) signals at zero frequency in an RF receiver unit, such as RF receiver unit **102** of system **100** (FIG. **1**).

Once coarse frequency offset corrections have been made, operations **406** through **420** may be performed. Operation **406** performs an autocorrelation using long training symbols **107** and a delayed version of the long training symbols to produce a first correlation output. In one embodiment, operation **406** may perform the autocorrelation with long training symbols delayed by one duration. Operation **408** performs an autocorrelation using long training symbols **107** and a delayed version of the long training symbols to produce a second correlation output. In one embodiment, operation **408** may perform the autocorrelation with long training symbols delayed by two durations. Operations **406** and **408** may be performed in parallel using substantially the same long training symbols or symbol stream. In one embodiment, operation **406** may be performed by autocorrelation element **216** (FIG. **2**), and operation **408** may be performed by autocorrelation element **226** (FIG. **2**).

Operation **410** may perform a moving average on the correlation outputs generated by operation **406**, and in one embodiment, may perform an integration over 1.5 long training symbol durations. Operation **412** may perform a moving average on the correlation outputs generated by operation **408** and in one embodiment, may perform an integration over 0.5 long training symbol durations. Operation **414** extracts the phase angle from the complex outputs generated by operations **410** and **412** to produce first and second phase shift estimates. Operation **416** may adjust the second phase shift estimate by a multiple of 2π when the difference between the first and second phase shift estimates exceeds π. In one embodiment, operation **410** may be performed by moving average element **218** (FIG. **2**), operation **412** may be performed by moving average element **228** (FIG. **2**), operation **414** may be performed by angle extractors **220** (FIG. **2**) and **230** (FIG. **2**), and operation **416** may be performed by phase corrector **208** (FIG. **2**).

Operation **418** may combine the first and second phase shift estimates to generate a frequency-offset estimate. In one embodiment, operation **418** may convert the first and second phase shift estimates to first and second frequency estimates, and may weight the frequency estimates before adding the weighted frequency estimates together to generate the frequency offset estimate. In one embodiment, operation **418** may be performed by summator **206** (FIG. **2**) using weights **210** (FIG. **2**).

In operation **420**, the frequency-offset estimate generated in operation **418** may be used to rotate the phase of subsequent data symbols of an OFDM packet prior to performing an FFT on the data symbols. In one embodiment, operation **420** may be performed by phase rotator **141** (FIG. **1**).

Thus, an orthogonal frequency division multiplexed (OFDM) receiver and method has been described that may achieve improved frequency synchronization. The system and method may utilize a two-channel frequency offset estimation that generates a fine frequency offset by performing concurrent autocorrelations on training symbols delayed by differing durations. The fine frequency offset estimate may be used to rotate the phase of OFDM data symbols prior to performing a FFT on the data symbols.

The foregoing description of specific embodiments reveals the general nature of the invention sufficiently that others can, by applying current knowledge, readily modify and/or adapt it for various applications without departing from the generic concept. Therefore such adaptations and modifications are within the meaning and range of equivalents of the disclosed embodiments. The phraseology or terminology employed herein is for the purpose of description and not of limitation. Accordingly, the invention embraces all such alternatives, modifications, equivalents and variations as fall within the spirit and scope of the appended claims.

What is claimed is:

1. A parallel-channel frequency-offset estimator to generate a frequency offset estimate comprising:

a first autocorrelation element to perform a first autocorrelation on a serial symbol stream of training symbols delayed by a first duration to produce a first correlation output;

a second autocorrelation element to perform a second autocorrelation on the serial symbol stream delayed by a second duration to produce a second correlation output;

a first moving average element to perform a first moving average on the first correlation output for use in generating a first phase shift estimate; and

a second moving average element to perform a second moving average on the second correlation output for use in generating a second phase shift estimate,

wherein the first duration is a duration of one of the training symbols, and the second duration is twice the first duration, and wherein the first moving average element performs the first moving average over approximately one and a half durations, and the second moving average element performs the second moving average over approximately one-half durations on the second correlation output.

2. The frequency-offset estimator of claim **1** wherein the frequency offset estimate is a fine frequency offset estimate and is applied to a phase rotator to rotate the phase of data symbols of an orthogonal frequency division multiplexed (OFDM) packet prior to performing a Fast Fourier Transform (FFT).

3. The frequency-offset estimator of claim **1** further comprising a phase correction element to adjust the second phase shift estimate by a multiple of 2π when a difference between the first and second phase shift estimates exceed π.

4. A two-channel freguency offset estimator to generate a frequency offset estimate comprising:

a first autocorrelation element to perform a first autocorrelation on a serial symbol stream of training symbols delayed by a first duration to produce a first correlation output;

a second autocorrelation element to perform a second autocorrelation on the serial symbol stream delayed by a second duration to produce a second correlation output;

a first moving average element to perform a first moving average on the first correlation output for use in generating a first phase shift estimate;

a second moving average element to perform a second moving average on the second correlation output for use in generating a second phase shift estimate; and

a summator to combine the first and second phase shift estimates to generate a frequency offset estimate, wherein the summator multiples the first phase shift estimate by $w_1/2\pi T$ to generate a first weighted frequency estimate, and multiples the second phase shift estimate by $w_2/4\pi T$ to generate a second weighted

frequency estimate, and combines the first and second weighted frequency estimates to generate the frequency offset estimate, wherein w_1 and w_2 are weights and T is the duration.

5. The frequency-offset estimator of claim 3 wherein the frequency offset estimate is applied to a phase rotator to shift a phase of symbols of an orthogonal frequency division multiplexed (OFDM) packet prior to performing a Fast Fourier Transform (FFT), the phase shift being held constant for performing the FFT on subsequent data symbols of the OFDM packet.

6. The frequency-offset estimator of claim 1 wherein the training symbols are sampled long training symbols comprised of a plurality of modulated subcarriers having known training values.

7. The frequency-offset estimator of claim 6 wherein the long training symbols are periodic having a period equal to the duration.

8. The frequency-offset estimator of claim 1 wherein further comprising;

a conjugation element to generate a complex conjugate of the training symbols.

9. The frequency-offset estimator of claim 1 wherein the first autocorrelation element multiples the training symbols with a complex conjugate of the training symbols delayed by approximately one duration, and

wherein the second autocorrelation element multiples the symbol stream of training symbols with a complex conjugate of the symbol stream of training symbols delayed by approximately two durations.

10. The frequency-offset estimator of claim 1 wherein the first duration is a duration of one of the training symbols, and the second duration is twice the first duration, and wherein the first moving average element performs a first integration over 1.5 symbol durations and produces a first complex value, wherein the second moving average element performs a second integration over 0.5 symbol durations and produces a second complex value,

and wherein the frequency-offset estimator further comprises:

a first angular extraction element to extract the first phase shift estimate from the first complex value; and

a second angular extraction element to extract the second phase shift estimate from the second complex value.

11. The frequency-offset estimator of claim 1 wherein the frequency offset estimate is a coarse frequency offset estimate to adjust a frequency for down-converting an IF input signal to the serial symbol stream.

12. The frequency-offset estimator of claim 11 wherein the serial symbol stream is comprised of sampled short training symbols modulated on a portion of a plurality of subcarriers, the short training symbols having known training values.

13. A method for frequency synchronization of an orthogonal frequency division multiplexed (OFDM) signal comprising:

generating a frequency offset estimate using first and second phase shift estimates, the first phase shift estimate generated from a serial symbol stream of training symbols with the symbol stream delayed by approximately a first duration, the second phase shift estimate generated from the serial symbol stream with the symbol stream delayed by a second duration, wherein the first duration is a duration of one of the training symbols, and the second duration is twice the first duration, and wherein integrating the first correlation output includes integrating the first correlation output over approximately one and a half durations, and wherein integrating the second correlation output includes integrating the second correlation output over approximately one-half durations.

14. The method of claim 13 wherein generating comprises: autocorrelating the serial symbol stream of training symbols with the symbol stream delayed by approximately the first duration to produce a first correlation output; autocorrelating the serial symbol stream with the symbol stream delayed by the second duration to produce a second correlation output; integrating the first correlation output to generate the first phase shift estimate; integrating the second correlation output to generate the second phase shift estimate; and combining the first and second phase shift estimates to generate the frequency offset estimate.

15. The method of claim 14 further comprising:

rotating a phase of data symbols of an OFDM packet by applying the frequency offset estimate to a phase rotator to rotate the phase of input symbols by an amount of phase shift based on the frequency offset estimate prior to performing an FFT on the data symbols; and

holding the amount of phase shift constant for performing the FFT on the data symbols.

16. The method of claim 13 further comprising adjusting the second phase shift estimate by a multiple of 2π when a difference between the first and second phase shift estimates exceed π.

17. A method for frequency synchronization of an orthogonal frequency division multiplexed (OFDM) signal comprising:

generating a frequency offset estimate using first and second phase shift estimates, the first phase shift estimate generated from a serial symbol stream of training symbols with the symbol stream delayed by approximately a first duration, the second phase shift estimate generated from the serial symbol stream with the symbol stream delayed by a second duration,

wherein generating comprises:

autocorrelating the serial symbol stream of training symbols with the symbol stream delayed by approximately the first duration to produce a first correlation output;

autocorrelating the serial symbol stream with the symbol stream delayed by the second duration to produce a second correlation output;

integrating the first correlation output to generate the first phase shift estimate;

integrating the second correlation output to generate the second phase shift estimate; and

combining the first and second phase shift estimates to generate the frequency offset estimate, and

wherein combining includes multiplying the first phase shift estimate by $w_1/2\pi T$ to generate a first weighted frequency estimate; multiplying the second phase shift estimate by $w_2/4\pi T$ to generate a second weighted frequency estimate; and summing the first and second weighted frequency estimate to generate the frequency offset estimate, wherein w_1 and w_2 are weights and T is the duration.

18. The method of claim 13 wherein the training symbols are sampled long training symbols comprised of a plurality of modulated subcarriers having known training values.

19. The method of claim 13 further comprising:

generating a complex conjugate of the training symbols; and

delaying the training symbols at least by the duration.

20. An orthogonal frequency division-multiplexed (OFDM) receiver system comprising:

a dipole antenna to receive signals that include an OFDM packet;

an RF receive unit to convert the OFDM packet to a stream of symbols;

a data symbol processing unit to perform a Fast Fourier Transform (FFT) on the stream of symbols to generate a decoded bit stream; and

a parallel-channel frequency offset estimator to generate a frequency offset estimate using training symbols of the stream of symbols to rotate a phase of data symbols of the OFDM packet prior to performing the FFT,

wherein the parallel-channel freguency offset estimator comprises:

a first autocorrelation element to perform a first autocorrelation on a serial symbol stream of training symbols delayed by a first duration to produce a first correlation output;

a second autocorrelation element to perform a second autocorrelation on the serial symbol stream delayed by a second duration to produce a second correlation output;

a first moving average element to perform a first moving average on the first correlation output for use in generating a first phase shift estimate; and

a second moving average element to perform a second moving average on the second correlation output for use in generating a second phase shift estimate, wherein the first duration is a duration of one of the training symbols, and the second duration is twice the first duration, and wherein the first moving average element performs the first moving average over approximately one and a half durations, and the second moving average element performs the second moving average over approximately one-half durations on the second correlation output.

21. The OFDM receiver system of claim **20** wherein the data symbol processing unit includes a phase rotator responsive to the frequency offset estimate, and wherein the two-channel frequency offset estimator further comprises:

a summator to combine the first and second phase shift estimates to generate the frequency offset estimate.

22. The OFDM receiver system of claim **21** wherein the data symbol processing unit further includes a phase correction element to adjust the second phase shift estimate by a multiple of 2π when a difference between the first and second phase shift estimates exceed π.

23. An orthogonal frequency division multiplexed (OFDM) receiver system comprising:

a dipole antenna to receive signals that include an OFDM packet;

an RF receive unit to convert the OFDM packet to a stream of symbols;

a data symbol processing unit to perform a Fast Fourier Transform (FFT) on the stream of symbols to generate a decoded bit stream; and

a two-channel freguency offset estimator to generate a freguency offset estimate using training symbols of the stream of symbols to rotate a phase of data symbols of the OFDM packet prior to performing the FFT,

wherein the data symbol processing unit includes a phase rotator responsive to the frequency offset estimate, and wherein the two-channel frequency offset estimator includes:

a first autocorrelation element to perform a first autocorrelation on a symbol stream of training symbols delayed by a first duration to produce a first correlation output;

a second autocorrelation element to perform a second autocorrelation on the symbol stream of training symbols delayed by a second duration to produce a second correlation output;

a first moving average element to perform a first moving average on the first correlation output for use in generating a first phase shift estimate;

a second moving average element to perform a second moving average on the second correlation output for use in generating a second phase shift estimate; and

a summator to combine the first and second phase shift estimates to generate the frequency offset estimate, and

wherein the summator multiples the first phase shift estimate by $w_1/2\pi T$ to generate a first weighted frequency estimate, and multiples the second phase shift estimate by $w_2/4\pi T$ to generate a second weighted frequency estimate, and combines the first and second weighted frequency estimates to generate the frequency offset estimate, wherein w_1 and w_2 are weights and T is the duration.

24. An article comprising a storage medium having stored thereon instructions, that when executed by a computing platform, result in:

autocorrelating a serial symbol stream of training symbols with the symbol stream delayed by approximately a first duration to produce a first correlation output;

autocorrelating the serial symbol stream with the symbol stream delayed by a second duration to produce a second correlation output;

integrating the first correlation output to generate a first phase shift estimate;

integrating the second correlation output to generate a second phase shift estimate; and

combining the first and second phase shift estimates to generate a frequency offset estimate, wherein the first duration is a duration of one of the training symbols, and the second duration is twice the first, duration, and wherein integrating the first correlation output includes integrating the first correlation output over approximately one and a half durations, and wherein integrating the second correlation output includes integrating the second correlation output over approximately one-half durations.

25. The article of claim **24** wherein the instructions further result in rotating a phase of data symbols of an orthogonal frequency division multiplexed (OFDM) packet by applying the frequency offset estimate to a phase rotator to rotate the phase of input symbols by an amount of phase shift based on the frequency offset estimate prior to performing an FFT on the data symbols.

26. The article of claim **25** wherein the instructions further result in:

holding the amount of phase shift constant for performing the FFT on the data symbols,

and resulting in frequency synchronization of an orthogonal frequency division multiplexed (OFDM) signal that includes the OFDM packet.

* * * * *